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RECLAMATION OF PYRITIC WASTE

by

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Reclamation of 8 hectares of disturbed mine land began in 1976. Fair to good vegetative cover had been established on over 90 percent of the area by 1982. To assure success of the vegetation, yearly maintenance of the more toxic areas has been required. Maintenance includes addition of fertilizer and limestone, and in the worst area, irrigation during drought periods. Weeping lovegrass (Eragrostis curvula) and Fescue (Ky-31, Festuca elatior var. arundenacea) have been the most successful vegetation.

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Abstract

The reclamation of land used for the disposal of pyritic mine waste utilizing sewage sludge as a soil conditioner has been studied in laboratory greenhouse studies and a full-scale demonstration project. Analysis of samples revealed that some of the mining waste had a pH as low as 1.8, and copper and zinc content as high as 10 mg/g, and 2 mg/g, respectively.

Greenhouse column studies showed that mine waste treated with sewage sludge, agricultural limestone, and fertilizer supported a good grass growth and improved the quality of the leachate generated.

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Introduction

Background

Between 1880 and 1923 three deep shaft pyrite mines (Arminius, Boyd Smith, and Sulphur) were in operation along Contrary Creek, Louisa County, Virginia. Over five and one-half million tonnes (six million tons) of ore were produced during this time. In addition, large volumes of wastes, with a high pyritic content, were produced from the mines and ore processing operations. These wastes were dumped indiscriminately along the creek and resulted in the denuding of approximately 12 hectares (30 acres) of land and the polluting of the creek with acid mine drainage (AMD) (Table 1). The land was still denuded in 1976. During this time span large volumes of waste had eroded into the stream bed further aggravating the AMD problem.

In 1975 the U.S. Environmental Protection Agency (EPA) and the Virginia State Water Control Board (SWCB) entered into a cooperative project to demonstrate how sewage sludge could be used to assist in the establishment of vegetation on toxic mine waste, and in-turn, reduce erosion and AMD production. The local Soil Conservation Service, USDA, (SCS) served as a consultant throughout the study. The Sulphur and Boyd Smith mine areas were selected for study since the Arminius mine was to be reclaimed by the owners. In addition to this demonstration study, a pilot plant research effort consisting of a series of column studies was conducted to evaluate, under controlled conditions, the effect treating pyritic mine waste with sludge would have on leachate AMD and heavy metal concentration. This pilot-plant study was conducted in the greenhouse of the U.S. EPA Test and Evaluation Facility in Cincinnati, Ohio.

Table 1. Chemical Characteristics of Water at the Mouth of Contrary Creek - 1974

Variable	Concentration	Variable	Concentration
pH	3.3	Cu, mg/	1.2
Acidity ($CaCO_3$), mg/	169	Zn, mg/	3.5
SO_4, mg/	267	Pb, mg/	0.05
Fe, mg/	23.1	Mn, mg/	1.5

Average of samples taken during 1974

Sewage Sludge as a Soil Amendment

Sewage sludge has been considered to be a desirable soil amendment to assist in the reclamation of drastically disturbed lands for some time .[1] The sludge contains organic matter and nutrients that are often lacking in disturbed lands and, thus, can be used to improve the chemical and physical properties of the waste material, inactivate heavy metals, and make it more suitable for the establishment of vegetation. A land surface with a good vegetative cover is less subject to erosion. At the time the demonstration study began in 1975, several investigations on a small scale had been conducted to assess the utilization of sludge for surface mine reclamation, however, no attempts had been made to reclaim extremely acidic mine waste. Thus, it was the purpose of this study to demonstrate how two environmental problems (i.e., mine waste and municipal sludge) could enter into a symbiotic relationship whereupon the sludge could be applied to mine wastes to facilitate its reclamation and reduce the environmental insult.

Column Studies

One of the objectives of the column studies was to determine the physical and chemical quality of leachate generated from test columns containing a high acidic mine waste and utilizing sewage sludge as the primary waste ameliorator. The mine waste was treated in a manner simulating the conditions of the full scale demonstration study. Sludge, agricultural limestone and fertilizer application rates used in the column studies were based on those used during the demonstration study. Climatological conditions of the demonstration site were also simulated. A sample of mine waste, representing material with the highest pyrite content (Table 2), was collected from the Sulphur Mine Site, air dried, screened and placed in a 0.3 m (1.0 ft) diameter acrylic column and compacted to a density similar to that noted at the demonstration site. Six columns were prepared with 138-156 kg (304-343 lb)

Table 2. Results of Analysis of Pyrite Mining Waste*

pH, (1:1 slurry)	1.8	Iron, mg/g	200
Potassium, ppm	3.7	Copper, mg/g	10
Calcium, ppm	146	Lead, mg/g	4
Magnesium, ppm	174	Zinc, mg/g	2
Phosphorus, ppm	73.2		
Sodium, ppm	76.8		
Organic carbon, %	2.2		
Lime requirement, tonnes of limestone/1100 Tonnes material[a]	24		

* Details on the methods used for the analysis are given in reference [2].

[a] One tonne = 2,200 lb

of mine waste in each column (approximately 1.2 m (4 ft) in depth). Two columns contained untreated raw waste and served as controls. The four remaining had mine waste treated with limestone, sludge and fertilizer (Figure 1). The application rate of limestone used, 440 tonnes/ha (196 tons/ac), was based on the soil analysis of the mine waste (Table 2) and the quantity required to treat the upper 15.2 cm (6 in.) of waste. The municipal sludge quantity, 709 tonnes/ha (315 tons/ac), was similar to that used in the field demonstration. An analysis of the sludge was performed, the results of which are shown in Table 3. A 15-15-15 fertilizer was used at a rate of 1.1 tonnes/ha (0.5 tons/ac), similar to that utilized in the field demonstration. In two of the columns, the sludge, fertilizer, and limestone were mixed with the top 15.2 cm (6 in.) of mine waste in the column. This treatment was used in the full demonstration. In the remaining two columns, limestone was mixed into the upper 15.2 cm (6 in.) of mine waste, and a mixture of fertilizer and sludge was placed as a layer on top. The columns were seeded with fescue (Ky-31, Festuca elatior var. arundinacea) and weeping lovegrass (Eragrostis curvula) at application rates of 67.3 Kg/ha (60 lb/ac) and 2.2 Kg/ha (2 lb/ac), respectively.

As previously mentioned, the column studies were conducted in a greenhouse

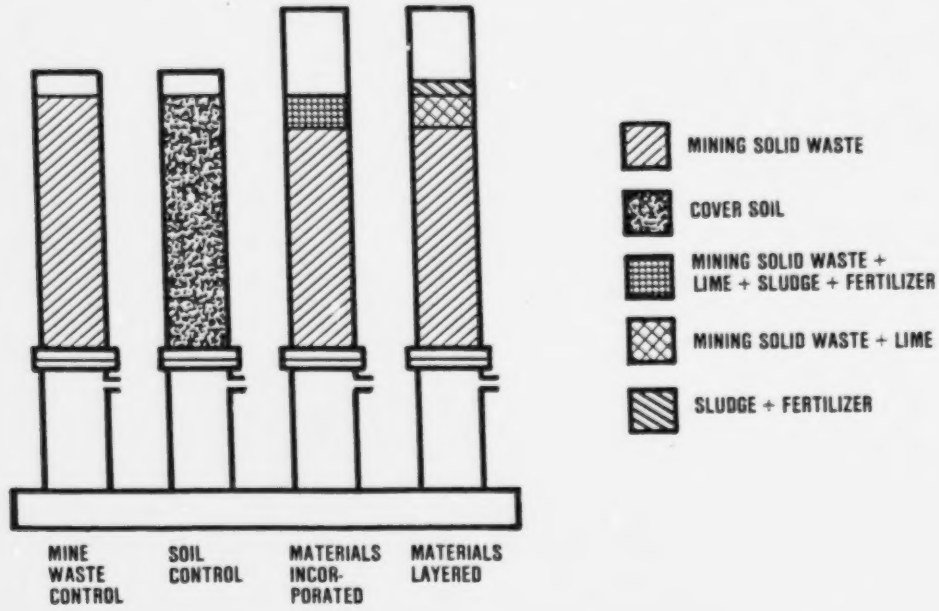

FIGURE 1. CONTENTS OF COLUMNS IN PILOT PLANT STUDY

in which the climatological conditions maintained throughout the studies were based on five-year mean monthly precipitation, temperature, and humidity data for the Virginia demonstration study area as recorded by the National Oceanic and Atmospheric Administration (NOAA).[3] Climatic conditions representative of the Contrary Creek area during the months of May through October were simulated. Ten-year, 24-hour storm events were simulated during weeks 9, 18, 20, and 24 of the 24-week study period. Data derived from an isoplethic map illustrating rainfall occurring in the United States during ten-year, 24-hour events indicated that this occurrence in the Virginia study area resulted in approximately 14 cm (6 in.) of rainfall. Distilled water was added to the columns weekly to simulate the rainfall conditions characteristic of the Virginia demonstration study site. Approximately 24-hours after water had been applied to the columns, leachate samples were collected from each column and analyzed for acidity, pH, iron, copper, lead, and zinc concentrations. From this information, load data were calculated and evaluated.

Since all of the test columns were duplicated, a paired observation t-test was used to determine whether the means of the data from the columns could be considered from the same population. The calculated t values were found in all cases to be less than the tabular value at the 95% confidence level; therefore, the data from the duplicates were combined and considered as one. The same statistical procedure was repeated to compare the control columns to the experimental columns. In each case, the calculated t statistic exceeded the tabular value at the 95% confidence level; therefore, it was concluded the characteristics of the experimental columns were indeed different from those of the control columns.

The acidity ($CaCO_3$ bases) of the leachate from the untreated pyritic waste columns (controls) ranged from a load of 44 g/day (0.1 lb/day) to over 500 g/day (1.1 lb/day), averaging approximately 172 g/day (0.4 lb/day). Maximum acidity loads correlated with the increased amounts of water applied to the columns to simulate 10-year, 24-hour storm events. Correspondingly, the pH values of leachate from these control columns ranged from 1.2 to 2.1. Iron, copper, and zinc loads averaged approximately 57 g/day (0.13 lb/day), 530 mg/day (0.001 lb/day), and 47 g/day (0.1 lb/day), respectively, with maximum values also corresponding to the simulated storm events. Lead, however, averaged only 11 mg/day (0.000022 lb/day) and remained relatively constant throughout the study period.

In comparison to the mining waste control columns, the incorporation of lime, fertilizer and sludge within the top 15.2 cm (6 in.) of the pyritic waste produced a dramatic effect on the quality of the leachate. A 77% decrease in acidity was observed when compared to the control. The copper and zinc loads in the leachate decreased approximately 57 and 67%, respectively, over the course of the study period. Levels of iron in the leachate also decreased. Overall, a 70% decrease in the mean iron load from these experimental columns compared to the control columns was noted. The lead load decreased 53%.

Mixing lime into the top 15.2 cm (6 in.) of the mine waste and then placing a mixed layer of fertilizer and sludge over this also affected the

quality of leachate generated. The overall acidity load of the leachate from these columns was approximately 65% less than in the untreated control columns. The pH of the leachate rose from an initial reading of 1.6 to approximately 2.2 at week seventeen with a subsequent decrease to 1.6 after simulated storm events at weeks 18, 20, and 24. In comparison with the untreated control columns the leachate from the treated columns exhibited 60, 43, 51 and 58% lower loads of iron, copper, zinc, and lead, respectively.

All four of the sludge treated columns supported grass growth whereas the untreated mine waste did not. After six months the grass on the sludge treated columns had reached an approximate height of 0.3 m (1 ft). In contrast, a column containing uncontaminated soil from near the demonstration site had produced grass approximately 1.1 m (3.5 ft) high. It can be concluded that the grass grown in the sludge treated mine waste was still under some stress.

As noted in Table 4, the results of these column studies produced strong evidence that a sludge/limestone treatment of mine waste would significantly improve the quality of the leachate. In addition, it was shown that the treatment modified the physical and chemical properties of the surface of the mine waste such that a grass cover could be established.*

Table 3. Metal and Organic Carbon Analysis of Sludge Used in Column Studies

Variable Analyzed[a]	Concentration (mg/g dry wt)
Copper	9.47
Nickel	1.35
Iron	122
Zinc	7.16
Cadmium	0.22
Lead	8.12
Moisture Content	78%
Organic Carbon	56.3%

[a]Metals were analyzed by atomic absorption spectroscopy, organic carbon analysis by low temperature ignition.

* A complete discussion of the column studies is available in reference [2].

Table 4. Decrease in Pollutant Load in Treated Mine Waste as Compared to the Untreated Mine Waste Control

	Percent	
	Incorporated Lime/Sludge/ Fertilizer into Mine Waste	Fertilizer/Sludge Layered Over limetreated waste
Acidity	77	65
Copper	57	43
Iron	70	60
Lead	53	58
Zinc	67	51

Demonstration Project

Site Characteristics

The Sulphur Mine Site was the worst of the three mine sites in the Contrary Creek watershed (Figure 2). Approximately 6 ha (15 ac) of land were covered with mine waste which had drastically altered the natural contours. The Sulphur mine area was divided into six subareas for reclamation planning (Table 5). The tailings area was by far the worst area in the project due to high levels of pyrite in the waste, and severe disturbance to the natural topography. In addition, a part of this site was perched along the stream bank and the site had very steep outer slopes. Some of the tailings dredged from the stream bed and placed along the bank also had a high pyrite content.

In contrast, the Boyd Smith Mine Site, approximately 2 ha (5 ac), was not nearly as severe. There was no profuse amount of pyritic material in the waste.

Reclamation

The reclamation plan called for the clearing of the waste areas of snags, stumps, brush, and rubbish. The areas were then graded and smoothed to approximate the natural contours. An estimated 67,000 cubic meters (87,600 yd^3) of material were moved. Old pits and shaft entrances at the Sulphur Mine were filled. Construction of diversions and waterways to shorten slopes and to minimize runoff infiltrating into the mine waste and underground working was done concurrently with the grading. At the Boyd Smith Mine the main drainageway traversing the site was excavated of mine waste, and realigned. A drainage diversion was constructed on each side of the site.

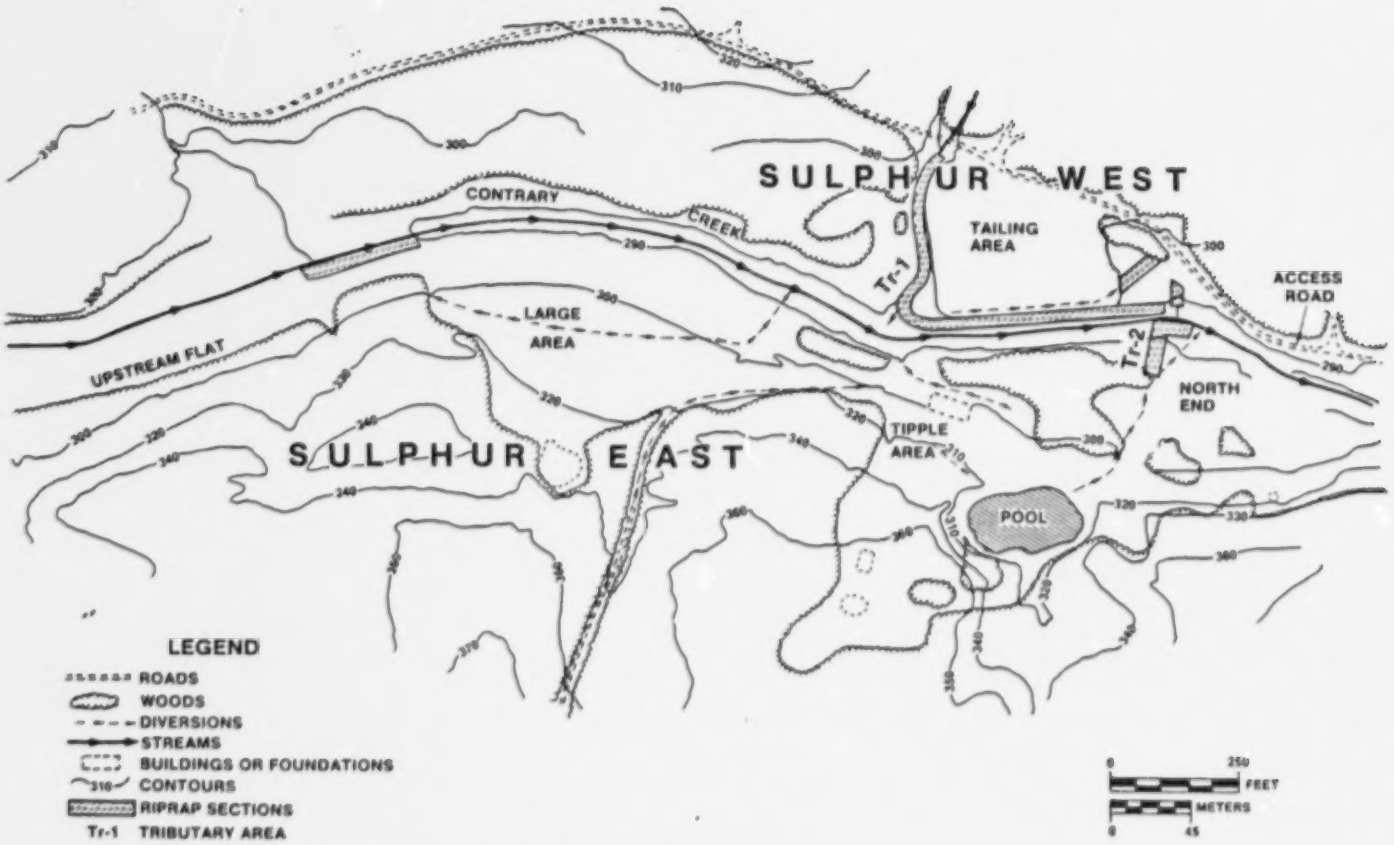

FIGURE 2. VARIOUS WORK AREAS OF SULPHUR MINE SITE
AT CONTRARY CREEK DEMONSTRATION SITE

At the Sulphur Site the channel of Contrary Creek was excavated to remove the mine waste. The streambed was also relocated and straightened in places. Approximately 1400 tonnes (1540 tons) of granite stone were used to stabilize the stream banks. Further details on the reclamation procedures are available in reference [4].

Application of Sludge and Other Soil Amendments

After evaluating several sources of sludge, the District of Columbia was selected. The District was willing to deliver the sludge to the project site free of charge.

Table 5. Characteristics of Sulphur and Boyd Smith Mine Sites

SULPHUR MINE

East Side Contrary Creek

Work Area	Size (ha)*	Conditions
Upstream Flat	0.55	Flood plain area along creek. Used to deposit mine waste dredged from creek when channel was cleaned and straightened.
Large Area	2.20	Denuded mine waste disposal area with numerous piles of waste. Poor surface drainage. Rill and gully erosion evident, collapsed mines shaft. Reclamation work included grading to gentle slope (8.5%) installation of diversion ditch, and filling of shaft.
Tipple Area	0.75	Very steep slope covered with mine waste below tipple ruins. Reclamation work: installation of diversion ditch and small amount of grading.
North End	0.85	Mine waste disposal area with one large pile of waste. Reclamation work: levels and grading of waste, improvement of tributary channel and riprap.
West Side Contrary Creek		
Tailing Area	1.15	Large tailing area retained by cribbing from creek, Rose about 9 meters (30 feet) above stream bed. Several large piles of waste severely eroded. Reclamation: grading of area, riprapping along creek, diversion ditch along creek.

Tributary Area	0.41	Flood plain area adjacent to creek and tributary. Reclamation: grading and riprapping of tributary.
		BOYD SMITH MINE
	2.03	Surface covered with 1 to 2 m (3 to 7 ft) of tailings. Tailings only moderately eroded and no profuse amount of pyritic materials. Tributary choked with tailings. Reclamation: grading, installing diversion ditch, cleaning and riprapping of tributary.

* To convert hectares (ha) to acres (ac) multiply by 2.471

Before delivery of sludge to the project site began the SWCB provided the Government of the District of Columbia with written authorization and all applicable hauling regulations from the Virginia Department of Highways and Transportation. Guidelines for the disposal of sludge were obtained from the Virginia Department of Health. The hauling route was designated so as to minimize travel through populated areas, and the hauling distance was approximately 275 kilometers (170 miles) per round trip. Sludge was hauled in 18-tonne-capacity (20-ton-capacity) trucks partially covered with tarpauline. Usually, 10 loads of sludge were hauled each day with five trucks making two trips each. Delivery of sludge began around mid-April and continued regularly for two months except for a few occasions when wet ground curtailed operations. Approximately 400 truckloads of sludge amounting to about 7250 tonnes (7990 tons) were delivered to both mine sites. Initially it was anticipated that some stockpiling of sludge might be necessary, but unusually dry weather during the spring of 1976 and an agreement with the hauler to deliver sludge on an as-needed basis minimized stockpiling. Virtually all of the sludge was dumped directly upon the regraded areas where it was to be incorporated.

Before sludge was spread and worked into the regraded areas, lime and fertilizer were applied to all areas to be reseeded. A spreader truck was used to apply lime to all areas except on steep slopes and soft places along the stream banks where it was necessary to hand spread. Lime was applied at the rate of 9 tonnes/ha (4 tons/ac), and 10-10-10 fertilizer was applied at the rate of 1120 kilograms/ha (1000 lbs/ac) to all areas. In addition to the 10-10-10 fertilizer, 38-0-0 (ureaform) fertilizer was applied at the rate of 448 kilograms/ha (400 lbs/ac) to the unsludged areas.

Sludge was generally allowed to dry for up to a week prior to spreading, but in some cases spreading was done a day or two after delivery. It would have been desirable for sludge to have dried longer before spreading, but this was not feasible due to time constraints. Bulldozers were used to spread the sludge to a thickness of approximately 10 cm (4 in.). It was found that spreading could be done much more efficiently by backdragging rather than pushing. A heavy-duty Rome disc drawn by a bulldozer was used to incorporate the sludge along with the other soil amendments into the spoil material to a depth of 8 to 16 cm (3 to 6 in.). Where the ground was too soft to support heavy equipment, a small disc pulled by a farm tractor was used to incorporate sludge. Approximately 1.2 ha (3 ac) of the Sulphur Site, including the Upstream Flat of Sulphur East and a few places along the stream banks that were too soft to support any equipment, did not receive sludge in 1976.

A total of 5443 tonnes (6000 tons) of wet sludge (78% moisture) were applied to 4.6 ha (11.4 ac) of the Sulphur Site and a total of 1814 tonnes (2000 tons) to 2 ha (5 ac) of the Boyd Smith Site. The actual dry tonnes applied are shown in Table 6.

Table 6. Sludge Application Rates at the Demonstration Site - 1976

Sulphur Site	260 dry tones/ha[a]
Boyd Smith Site	200 dry tonnes/ha

[a] To convert tonnes/ha to tons/ac multiply by 0.449

Special care was taken during all phases of the operation to prevent sludge from entering into Contrary Creek or any of its tributaries. Trucks were directed to dump a safe distance from all stream banks and in some places low berms were constructed as a further protection. There was concern that there might be a problem with sludge being washed into the main stream and tributaries in the event a heavy rain fell while sludge was drying, but it was found that sludge tended to cohere when wet and did not flow appreciably well. Where possible, some sludge was applied to stream banks but inaccessibility kept this to a minimum. Trucks were carefully cleaned after each dumping to prevent loss of sludge on public highways.

As part of the project monitoring, samples were collected from each truckload of sludge and composited into one daily sample during the 1976 work. There was little variation in the composition of the sludge from day to day, but the moisture content varied as much as 8 percent. This variation can mainly be attributed to the sludge being stored in the open for a day or so before hauling, the slight variation in moisture content of the sludge from

the treatment plant. Average concentrations of the constituents in the Contrary Creek sludge, based upon 40 composite samples collected during the 1976 work, are shown in Table 7.

Table 7. Average Concentrations of Constituents in the Sludge Used in the Demonstration Study at Contrary Creek in 1976 on Dry Weight Basis

Constituent	ppm
Alkalinity	17
Chlorine (Soluble)	8.1
Cadmium	17
Chrome	659
Copper	785
Iron	109,000
Lead	550
Mercury	5.05
Zinc	2,529
Nickel	29
Fluorine (Soluble)	0.73

The heavy metals content of the Blue Plains sludge is within the range of that reported for sludge from other municipal sewage treatment plants and tends to be lower than that from highly industrialized cities. The high iron content of the Blue Plains sludge is partly due to ferric chloride used in the treatment process. The median pH of the sludge was 6.5 and volatile solids averaged 51 percent. Fertilizer equivalent values were also determined for the sludge and averages for the composite samples in the summer of 1976 are shown in Table 8.

Table 8. Average Fertilizer Equivalents of Sludge Used at Contrary Creek in 1976 on Dry Weight Basis

Nutrient	Percent
Nitrogen, N	3.23
Phosphorus, P_2O_5	7.32
Potassium, K	0.32

Seeding

Seeding began in late June and was completed at both sites by early July. While it was realized that this was not the most favorable season for planting, it was not feasible to delay the seeding since the regrading and smoothing work had progressed considerably faster than expected. After all soil amendments had been incorporated, the seedbed was smoothed by dragging heavy timbers over rough areas as a final preparation. A tractor-drawn Brillion cultipacker was used to do all seeding except for steep banks and soft spots that had to be hand seeded. The seed formula included two grasses, Ky-31 fescue (67 kg/ha, 60 lb/ac) and red top (Agrostis alba) (5.6 kg/ha, 5 lb/ac) along with ladino clover (Trifalium repens) (5.6 kg/ha, 5 lb/ac) for a legume. Immediately after seeding, mulch comprised of small grain straw was applied at the rate of 5 tonnes/ha (2.2 tons/ac) with a mulching machine and tied down with emulsified asphalt.

After all construction was completed, several straw bales were staked in drainageways and along stream banks to control erosion until vegetation had a chance to become established. By late summer it was realized that additional erosion controls would be needed. Approximately 300 straw bales were placed at erosion prone areas on both sides of the Sulphur Site in October 1976.

1976 Results

The success of the 1976 seeding work was very limited. It was realized that late June and early July were not optimum times for planting and the problem was further compounded by below average rainfall during the remainder of the growing season. This was particularly so in July, and by the time a few heavy thunderstorms came in August, much of the grass that had germinated had died. Only in the more shaded areas did the grass show any degree of success.

Vegetation survival at the Sulphur Site was by far the poorest of the areas seeded. The only areas that showed any significant cover of grass by the end of the summer were some of the shaded areas on Sulphur East. The Large Area (Table 5) on Sulphur East produced a heavy growth of tomatoes (seeds were in the sludge) during the late summer, but after the first frost only a few patches of vegetation remained around the edges that had been shaded. Virtually no germination occurred on the Tailing Area of Sulphur West even though sludge had been applied heavily. None of the unsludged areas on either side of the Sulphur Site showed any signs of germination.

At the Boyd Smith Site the results of the 1976 work were more encouraging. A fair growth of vegetation had been established on some parts of the site, but the dry weather took its toll here also, despite the ground remaining somewhat wetter than the Sulphur Site. Sludge had been applied to all of the Boyd Smith Site, but of the seeds planted, only the Ky-31 showed any success.

By late summer it was apparent that complete reseeding would be necessary in the spring of 1977, and an abnormally cold fall further limited vegetative success. Overriding the weather problems was the fact that major portions of the Sulphur Site still remained highly toxic.

1977 Reseeding and Results

During the spring of 1977, work consisted of the application of additional lime and fertilizer, reseeding of both sites, and placing a new section of riprap at the Sulphur Site. Lime application rates were determined by titration analyses of composite soil samples. Lime was applied by truck at rates ranging from 13.3 to 31.2 tonnes/ha (6 to 14 tons/ac) on the Sulphur Site and at a rate of 9 tonnes/ha (4 tons/ac) on the Boyd Smith Site. Except for a small experimental plot, all remaining portions of both sites were treated with 10-10-10 fertilizer with the 38-0-0 ureaform again added to the severe areas where sludge had not been applied. The seed mixture was: Ky-31 fescue - 67.3 kg/ha (60 lb/ac), red top - 5.6 kg/ha (5 lb/ac), ladino clover - 2.2 kg/ha (2 lb/ac), Korean lespedeza (Lespedeza stipulacea) - 11.2 kg/ha (10 lb/ac), and weeping lovegrass - 2.2 kg/ha (2 lb/ac).

The spring of 1977 reseeding work was almost a complete failure primarily due to a severe drought which followed. Rainfall for the months of June through September was 22 cm (8.7 in.) below normal. By late summer, some of the upper reaches of Contrary Creek itself had completely ceased flowing. The extreme drought not only negated the spring seeding but also destroyed some of the meager patches of Ky-31 grass that had survived from the previous summer. The one encouraging note was the weeping lovegrass which came on in late July at the height of the drought. This drought-tolerant grass which had been sown for the first time in the spring of 1977 exhibited a vigorous growth on most of the Large Area of Sulphur East and the Boyd Smith Site. The lovegrass was most successful in the same general areas where scattered patches of Ky-31 had managed to take root in 1976. The lovegrass was the only vegetation from the

spring seeding that survived the summer, and it shows good survival to date. Sulphur West remained practically barren as well as several other smaller areas of Sulphur East. It was obvious by mid-summer that a major reseeding program would be necessary in the fall.

The fall work consisted of (1) spreading and incorporation of sludge on designated areas of the Sulfur Site; (2) liming, seeding, and mulching portions of both sites; and (3) modification of an existing beaver dam for a source of irrigation water at the Sulphur Site.

Approximately 1770 tonnes (1951 tons) (wet weight) of sludge was applied to 1.1 hectares (2.7 acres) on Sulphur West and to 0.5 hectare (1.2 acres) on Sulphur East which amounted to approximately 220 dry tonnes/ha (99 tons/ac). Sludge was applied to the Upstream Flat of Sulphur East for the first time. This area where the stream had been straightened was too soft to support heavy equipment when the 1976 work was done, but the extremely dry conditions of 1977 allowed the sludge trucks to dump directly on the areas of application.

The only area limed at this time was the Tailing Area of Sulphur West. Agricultural limestone was applied at the rate of 22 tonnes/ha (10 tons/ac). After sludge and lime had been applied, seed was incorporated with a grain drill. This method of seeding was used for all subsequent maintenance except for inaccessible areas that were hand seeded. The same seed formula and application rates were used as in the spring of 1977 seeding with the exception of ladino clover which was deleted from the seed mixture. A total of 3 hectares (7.4 acres) were reseeded at the Sulphur Site and 0.2 hectares (0.5 acres) were reseeded at the Boyd Smith Site. Mulch comprised of small grain straw was hand spread on approximately 2 hectares (5 acres) of newly seeded areas of the Sulphur Site and tied down by discing.

The results of the 1977 fall seeding were the most encouraging so far for the project. Heavy rains during the first week of November caused grass to germinate in places where no germination had been observed before. The heavy application of sludge on the Upstream Flat of Sulphur East and the Tailing Area of Sulphur West was undoubtedly also a major factor. Unfortunately, with the onset of cold temperatures, the grass did not have a chance to get a good start.

Despite the successes, some of the same barren areas at the Sulphur Site remained bare or showed meager growth of grass. It was obvious that more spot seeding would be necessary the following year.

1978 Maintenance Work and Results

After further soil analyses it was determined that approximately 1.6 hectares (4 acres) of the Sulphur Site would be reseeded during the spring season. No seeding was done on the stream banks where the ground was very soft and because a major reseeding program was planned for the fall of 1978. While there was risk that another severe drought would make this work futile, it was felt that gains could be made if a more normal season of rainfall

followed. Red top was excluded from the seed mixture. Limestone was applied to the reseeded areas only at the rate of 22.25 tonnes/ha (10 tons/ac).

A more normal season of rainfall during the summer of 1978 made the spring seeding quite successful, but some of the same problem areas persisted along the stream banks at the Sulphur Site. One of the more encouraging signs was the increasing grass cover that was establishing on the Tailing Area of Sulphur West. The Ky-31 fescue was still showing a vigorous growth and for the first time Korean lespedeza germinated. Numerous volunteer weeds also began to invade the Large Area of Sulphur East and the Boyd Smith Site. By this time it appeared that the Boyd Smith Site would require little additional seeding. The weeping lovegrass again achieved a vigorous growth during the hot summer months, and it appeared to be thriving in the Upstream Flat of Sulphur East where little other vegetation had ever germinated.

A total of 540 tonnes (600 tons) of sludge was stockpiled at three locations on the Sulphur Site for the fall maintenance. This was the first time that sludge was stockpiled for any appreciable time before application. Sludge can be handled much better the longer it dries, but there is, of course, extra work involved in transporting it from stockpiles to areas of application and there is some risk of heavy rain washing it out of stockpile areas. Sludge was hauled from stockpiles with an earthmoving pan and partially spread as it was released from the pan. Further smoothing was done with a bulldozer before sludge was disced in. Approximately 0.8 hectare (2 acres) on each side of the Sulphur Site was sludged with approximately 138 dry tonnes/ha (60 tons/ac). Limestone had been applied at rates ranging from 11 to 33 tonnes/ha (5-15 tons/ac) prior to sludging.

The seedbed of the unsludged areas was prepared with a small disc and the same seed formula was used as the previous spring except that rye was planted at the rate of 22 kg/ha (20 lbs/ac) for a nurse crop. A total of 1.62 hectares (4 acres) were seeded.

A small amount of rainfall in early October germinated the new seed, but when another dry spell followed and threatened the survival of the new grass, it was quickly decided to begin irrigation of the most critical areas. Water was pumped from an impoundment west of the Sulphur Site and applied to about 1 hectare (2.5 acres) five times over a three period. Approximately 2.54 cm (1 in.) of water was applied each time.

The results of the fall irrigation work were most beneficial. Grass germinated on some portions of the stream banks of Sulphur East and Sulphur West where no grass had ever sprouted before. The Ky-31 fescue which is a cool weather grass showed the most success. It was again obvious that the sludge was a major factor in promoting the growth of vegetation. Some of the previous problem areas remained barren despite the success of the fall seeding, indicating need for continued maintenance.

1979 Maintenance and Results

The maintenance program was continued in the spring of 1979 with spot seeding of 0.85 ha (2.1 ac) at the Sulphur Site and application of limestone and fertilizer. Because continued soil tests by the SCS had begun to suggest a strong association between bareness and potash deficiency, it was decided that a high potash fertilizer of the formula 6-6-12 would be used. In the initial reclamation work a high nitrate fertilizer of the formula 38-0-0 had been used. A total of 9.07 tonnes (10 tons) of 6-6-12 fertilizer were applied to all of the Sulphur and Boyd Smith Sites at the rate of 1121 kg/ha (1000 lbs/ac). Limestone was applied at rates ranging from 8.9 tonnes/ha (4 tons/ac) to 17.8 tonnes/ha (8 tons/ac) on reseeded areas of the Sulphur Site as determined by soil tests. All remaining portions of both sites were limed at the rate of 4.45 tonnes/ha (2 tons/ac).

A continuing improvement in the vegetative cover was apparent over most of the reclaimed areas during the summer of 1979. Notable areas of improvement were the Tipple Area of Sulphur East and in low lying areas of Sulphur West. Numerous varieties of weeds continued to invade the Large Area of Sulphur East along with at least two species of trees. Of the grasses sown, the Ky-31 fescue continued to be the dominant species with the lovegrass demonstrating its usual good growth in mid-summer. Both varieties of lespedeza produced only moderate growth and ground cover. Parts of the Tailing Area of Sulphur West, the North End of Sulphur East, and some of the stream banks still supported little or no vegetation and obviously remained highly toxic.

Although precipitation was generally abundant throughout Virginia during most of 1979, only 1.88 cm (0.74 in.) of rain fell on the project site in July. When the dry weather threatened the survival of the new grass and began to take its toll on some of the established parts of Sulphur West, irrigation was begun at once. The irrigation along with more normal rainfall during late summer maintained a relatively successful grass cover on Sulphur West.

Essentially the same maintenance was performed in the fall as had been applied in the spring except that sludge was again added to some of the problem areas that persisted. A small portion of the Boyd Smith Site which had remained barren and had started to extend into established vegetation was reworked. No seeding had been done at this site since the fall of 1977. Lime (8.9 - 22.25 tonnes/ha, (4-10 tons/ac)), and fertilizer (1121 kg/ha of 6-0-12, (1000 lb/ac)) were applied in early September to all of the Sulphur Site and that portion of Boyd Smith Site seeded.

Approximately 308 tonnes (340 tons) of sludge had been stockpiled at the Sulphur Site during August. After liming and fertilizing were complete, sludge was hauled with a dump truck to areas to be reseeded at each site and then spread. Although this did not incorporate the sludge to the depth normally desired and, in fact, left much of it at the surface, it appeared that the seed germinated quite well. Also, the limited amount of sludge used at this time minimized its possibility of being washed into the stream. About

82 dry tonnes/ha (37 tons/ac) of sludge was applied. This was the last application of sludge to any portion of the project.

A "tolerant" red fescue was added to the seed formula because it had been used in the reclamation work at the Arminius Site and had appeared to be successful. No legume was included, but Korean lespedeza was hand sown over the same areas in February of 1980.

Maintenance accomplished in the fall of 1979 was particularly successful in improving vegetative cover on the sites. By late fall the grass cover over the entire Sulphur Site looked healthier than ever, and new grass had sprouted on most of the reseeded areas. One notable area of pronounced improvement was the North End of Sulphur East. The continued use of sludge was judged to be a significant factor, along with abundant rainfall, in germinating the new grass. The high potash fertilizer may have also been a factor. The red fescue was moderately successful, but appeared to be vulnerable to drought.

1980 Maintenance

Lime and fertilizer were again applied to all of the Sulphur and the north side of the Boyd Smith Site in April and September of 1980. At each time lime was applied at the rate of 8.9 tonnes/ha (4 tones/ac) and fertilizer was applied at the rate of 1121 kg/ha (1000 lbs/ac). Fertilizer of the type 6-0-12 was used in the spring work, but after soil tests in August showed a decline in phosphate availability, 6-6-12 fertilizer was again used in the fall maintenance.

Abundant rainfall during April and May promoted a vigorous growth of vegetation over most of the reclaimed areas, but the sudden onset of another drought in June necessitated resumption of irrigation. Six applications of irrigation during July were essential in preserving vegetation on critical portions of the Sulphur Site. The 1980 drought did minimal damage to the overall project, but prohibited any significant gains in establishing vegetative cover during this growing season.

1981 Results

The 1980-1981 winter was very dry, but several heavy rains at crucial parts of the growing season resulted in good spring growth. The grass was bushhogged during the summer. Vegetative cover appeared to make good progress in 1981 even though overall precipitation for the year was considerably below normal.

1982

Since the funds for the project cease in July of 1982, a final application of amendments were applied in the spring. Based upon soil samples collected throughout the project area, and a desire to apply an "insurance" application of limestone and fertilizer, an application rate of 1121 kg/ha (1000 lbs/ac) of 5-10-10 fertilizer and 8.9 tonnes/ha (4 tonnes/ac) were applied to both the

Sulphur Site and the Boyd Smith Site. Abundant rainfall in the spring of 1982 continued to enhance the vegetative cover over virtually all portions of the project.

Soil Changes

Soil samples have been collected and analyzed throughout the life of the project. The results of these analyses have been used to determine the amount of fertilizer and limestone to be applied. In addition, they have been used to follow the changes that are occurring in the soil characteristics. A summary of these analyses appears in Table 9. The data show that the addition of sludge and limestone raised the pH and lowered the heavy metal concentration. Part of the reduction in heavy metal was undoubtedly due to an increase in pH, which results in a lower solubility of the metal. However, a portion of the reduction may be attributable to the sludge which tied up the metals.

Since only the top 15 cm (6 in.) of waste were treated, the lower level of waste was suspected to remain at a toxic level. Some limited soil sampling was conducted to verify this situation and, indeed, it was found that the lower levels had not been affected. For example, in one area with a good grass cover, the pH at 5 cm (2 in.) depth was 5.0, and at 30 cm (12 in.), 3.2.

Conclusions

The full scale demonstration project showed that on mine waste containing moderate amounts of pyrite, such as at the Boyd Smith Site, the application of sewage sludge, limestone, and fertilizer can be used successfully to develop a soil material that will support a good grass cover. Once established, additional application of limestone and fertilizer may not be necessary, but it is recommended that for a period of 5-10 years, close observations be kept on the area and additional soil amendments be applied if necessary.

On areas highly contaminated with pyrite waste, such as the west side of the Sulphur Mine, vegetation can be established utilizing sewage sludge, fertilizer, and limestone; however, these areas are very sensitive to drought and may require the addition of limestone and fertilizer, as well as irrigation, on an annual basis. The treatment used in this study was only mixed into the upper 15 cm (6 in.) of waste, below this layer the material was toxic to plants. Thus, the root system of the plants were very shallow, and during dry periods the plants died, if supplemental irrigation water was not applied. It is recommended under these situations that a soil layer be applied over the top of the waste, then the sludge and soil amendment applied.

Ky-31 fescue and weeping lovegrass were found to be the best grasses for reclamation under these conditions. The lovegrass was found to be drought tolerant and able to withstand lower pH, whereas, the fescue was the best all around and dominated under favorable conditions.

Table 9. Soil Data, pH, and Metals on Dry Weight Basis* (mg/kg)

Area-Date	pH	Cu	Fe	Pb	Mn	Zn	Al
SULPHUR WEST							
Tailing Area							
11-76	4.1	50	30		74	262	
6-77	3.1	62	34	--	17	82	132
3-78	5.1	0.1	7.8	0.2	6.8	6.6	1.0
6-78	5.9	1.0	24	0.2	3.6	1.5	2.4
7-79	4.4	--	--	--	--	--	--
10-79	3.6	--	--	--	--	--	--
2-80	4.9	0.2	0.4	0.2-**	2.6	3.4	1.0
8-80	6.1	--	--	--	--	--	--
7-81	7.2	0.3	0.1-	0.2	0.1	0.1	
2-82	5.6	0.2	0.1	0.2	0.8	0.02	2.0-
Tr-1							
11-76	3.7	288	220	4.6	152	3940	--
3-78	3.6	226	340	2.4	7.4	366	32
3-79	6.5	0.9	0.2-	0.002	2.9	1.6	1.0-
2-80	5.3	0.6	0.6	0.2-	4.8	17.8	2.0-
8-80	6.1	--	--	--	--	--	--
7-81	7.2	0.7	0.1-	0.4	26.0	24.0	--
2-82	5.6	0.3	0.4	0.2-	1.5	1.3	2.0
SULPHUR EAST							
Large Area							
11-76	5.5	8.6	4.2	--	31.4	18.8	
3-78	7.3	0.3	6.2	0.2	0.5	0.1	2.0
3-79	5.9	0.3	3.6	0.005	1.9	1.2	1.0-
2-80	5.2	0.2	0.8	0.2	1.7	3.4	2.0-
8-80	6.6	--	--	--	--	--	--
7-81	7.4	1.3	0.1	0.6	0.1-	0.8	--
2-82	6.4	0.4	0.1	0.2	0.6	0.54	2.0-
Tipple Area							
3-78	3.2	5.0	80	0.2	0.8	6.2	6.6
6-78	3.0	28	620	0.2-	3.0	24	100
3-79	5.9	0.1	0.6	0.001	3.9	2.0	1-
2-80	4.7	1.1	4.8	0.2-	4.6	10.2	2-
8-80	5.7	--	--	--	--	--	--
7-81	7.3	0.3	0.1-	0.2	0.1-	0.1	--
2-82	6.5	0.2	0.1	0.2-	0.04	0.26	2
BOYD SMITH							
11-76	5.4	0.7	0.6	--	30.6	19.6	
6-78	7.1	0.3	1.0	0.2-	1.6	0.8	1.2
3-79	5.7	1.1	0.2	0.011	7.0	19.6	1-
2-80	5.0	1.0	0.4	0.2-	6.0	12.6	2-
8-80	6.2	--	--	--	--	--	--
7-81	7.3	0.7	0.1-	0.2-	0.9	8.8	--
2-82	6.1	0.5	0.9	0.2-	7.4	1.6	4

* Water extraction of soluble salts for metals
** - Less than

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